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The Importance of Shared Environment in Mother–Infant Attachment Security: A Behavioral Genetic Study

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In a sample of 157 monozygotic and dizygotic twins, genetic and environmental influences on infant attachment and temperament were quantified. Only unique environmental or error components could explain the variance in disorganized versus organized attachment as assessed in the Ainsworth Strange Situation Procedure. For secure versus nonsecure attachment, 52% of the variance in attachment security was explained by shared environment, and 48% of the variance was explained by unique environmental factors and measurement error. The role of genetic factors in attachment disorganization and attachment security was negligible. Genetic factors explained 77% of the variance in temperamental reactivity, and unique environmental factors and measurement error explained 23%. Differences in temperamental reactivity were not associated with attachment concordance.

Behavioral genetic research on twins, siblings, and unrelated (adoptive or step) children have changed our views on child development drastically. Some proponents of the behavioral genetic approach have declared most findings on child development seriously flawed because they are based on traditional research designs focusing on between-family comparisons that confound genetic similarities between parents and children with supposedly shared environmental influences (Rowe, 1994). It has been argued that there is an urgent need to rethink radically the role of parents in child development (Harris, 1998; but see Collins, Maccoby, Steinberg, Hetherington, & Bornstein, 2000; Rose, 1995).

Considering the amount of evidence in favor of a major role for genetics in the development of behaviors, personality traits, and attitudes, one is inclined to emphasize the influences of genetics and unique environmental pressures more heavily than in the past. In a summary of the advances of behavior genetic research, McGuffin, Riley, and Plomin (2001) stated that behavior genetic findings consistently converge on the conclusion that ''genetic variation makes a substantial contribution to phenotypic variation for all behavioral domains'' (p. 1232). More specifically, they stated that most behaviors that have been studied show moderate to high heritability, and if environment plays a role, its contribution often is nonshared or unique because it makes people different from, instead of similar to, their relatives (see also Plomin, DeFries, McClearn, & McGuffin, 2001, p. 299). Parental behavior that stimulates similar developmental patterns across siblings (shared environment) seems to be elusive, and important behaviors or characteristics without a substantial genetic component seem to be rare. Nevertheless, in several behavioral genetic studies a contribution of the shared environment has been found, in particular when they included infants and young children (Leve, Winebarger, Fagot, Reid, & Goldsmith, 1998; McCartney, Harris, & Bernieri, 1990; Riese, 1990). In the current study further evidence is presented for a seemingly unusual combination of a small or negligible genetic component and a large (shared and nonshared) environmental component concerning patterns of infant attachment behavior.

From attachment theory, strong predictions about the role of shared environment in the development of organized infant attachment strategies may be

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The idea for a behavior genetic analysis of the combined Leiden and London twin infant attachment and temperament data originated with Marinus van IJzendoorn. We acknowledge the assistance of Julia van Os in collecting and coding some of the data. We would like to express our thanks to Dorret Boomsma and Caroline van Baal of the Netherlands Twin Register for their support. This study serves as part of a dissertation to be submitted by the first author to Leiden University in partial fulfillment of the requirements for the doctoral degree.

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derived (Main, 1999). Attachment theory stresses the influence of parental attachment representations and parenting behavior (O'Connor & Croft, 2001; O'Connor, Croft, & Steele, 2000). From an evolutionary viewpoint, it seems to make sense that infants do not inherit a fixed attachment behavior pattern but are endowed with flexible ways to adapt to changing circumstances and especially to changing or conditional parenting strategies (Belsky, 1999; Main, 1999; Simpson, 1999). Secure, resistant, and avoidant attachment behavior patterns (Ainsworth, Blehar, Waters, & Wall, 1978) are thought to result from the infants' experiences with (in)consistently sensitive or consistently insensitive parents. This type of sensitivity would in turn be determined by parents' diverging (secure, avoidant, or resistant) childhood attachment experiences and, more crucially, their subsequent mental representations of attachment (Main, Kaplan, & Cassidy, 1985; Van IJzendoorn, 1995a). This seems to imply a large role for the shared environment, not only for attachment security but also for the organized nonsecure attachment patterns, that is, resistant and avoidant attachment.

The transmission of attachment from parents to their infants may nevertheless at least be partly mediated by a genetic pathway (Main, 1999). Although several studies have provided support for the basic model of causal relations among parental attachment representations, parental sensitivity, and infant attachment strategy (Main et al., 1985), a large and quantifiable transmission gap of about 75% of the intergenerational transmission remains to be closed (Van IJzendoorn, 1995b). If parents' attachment representations are found to be strongly associated with infant attachment strategies (Hesse, 1999; Main, 1999), even when parental attachment representations are assessed before the birth of the infant (Fonagy, Steele, & Steele, 1991), and at the same time equally strong associations between parenting behavior and infant attachment cannot be found (DeWolff & Van IJzendoorn, 1997), the gap between parent and infant attachment should be closed in other ways. Several attempts to close the gap have been made by assessing attachment security and parental sensitivity during long observational sessions in the natural setting (e.g., Pederson, Gleason, Moran, & Bento, 1998) or by measuring other mediating factors such as mind-mindedness (Meins, 1999). Nevertheless, the transmission gap could not be closed this way.

Of course, genetics seems a plausible candidate for closing the transmission gap because parents and infants share 50% of their genes, and intergenerational transmission of attachment may (partly) be based on transmission of genes from one generation to the next. More specifically, behavior genetic studies have documented that a large part of individual differences in the affective quality of parent–child relationships is influenced by active genotype–environment interactions (O'Connor & Croft, 2001). For example, genetic differences in temperament may provoke different environmental reactions, and may lead to diverging attachment behavior patterns. The genetic transmission of temperament may thus be partly responsible for the link between parent and infant attachment, and it may account for part of the transmission gap. In the current study, the heritability of temperament was investigated, and it was tested whether similarities in temperamental reactivity between twins are associated with concordance in attachment relationships to the same caregiver.

In a previous study on similarity of attachment in siblings (Van IJzendoorn et al., 2000) some evidence was found for the idea that mothers stimulate similar attachment relationships with siblings. Attachment theory suggests that brothers and sisters growing up in the same family are likely to relate in similar ways to their parents, at least when parental attachment representations and interactive styles remain stable across time. Attachment security was assessed for each sibling using the Strange Situation Procedure between 12 and 14 months after birth. Sibling relationships were found to be significantly concordant when classified as secure or nonsecure. Maternal insensitivity to both siblings (shared environment) was associated with concordance of sibling nonsecurity, which may be consistent with a substantial role for the shared environment, that is, for similarity in parenting style to both siblings. Siblings of the same gender were more likely to form concordant relationships with their mother than those of opposite gender. In the design of this study, the role of (shared and nonshared) environment was still confounded with the role of genetics because contrast groups with varying degrees of genetic relatedness were lacking. It was therefore impossible to address the question of heritability of attachment with a behavior genetic approach.

Twin studies provide a unique opportunity to test the similarity of siblings' attachment relationships under conditions of similar age and childrearing contexts, using established behavior genetic methods. Few studies have been performed on the attachment relationships of twins, and these have tended to involve relatively small samples. Ricciuti (1992) combined three small sample studies of twins (Goldberg, Perrotta, Minde, & Corter, 1986; see also

Goldsmith & Campos, 1990; Minde, Corter, Goldberg, & Jeffers, 1990; Vandell, Owen, Wilson, & Henderson, 1988) to test whether attachment classifications showed genetic influence. Ricciuti (1992) found 78% concordance of attachment security in 27 dizygotic (DZ) twin pairs and 66% concordance in 29 monozygotic (MZ) twin pairs; she therefore concluded that in this combined sample of 12- to 22-month-old twins, attachment security as assessed through the Strange Situation did not show genetic influence.

Finkel, Wille, and Matheny (1998) studied the similarity of attachment in twin pairs at the ages 18 and 24 months with an adapted separation–reunion procedure. They found 67% concordance of security in 34 MZ twins but only 38% concordance in 26 DZ twins. This percentage of DZ twin concordance is below chance (see Van IJzendoorn et al., 2000). The significant difference between DZ and MZ twin concordance indicated only ''modest rearing environment effects'' (Finkel et al., 1998, p. 7). Finkel and Matheny (2000) reported on the complete Louisville Twin Study of attachment. They found only 48% concordance in 108 DZ twin pairs, but 66% concordance in 99 MZ twin pairs. The concordance in DZ twins, however, is significantly lower than the 62% found on average in previous investigations on DZ twins and siblings (Van IJzendoorn et al., 2000). Finkel and her colleagues (Finkel et al., 1998; Finkel & Matheny, 2000) estimated that heritability of attachment is 25% and that the remaining variance may be attributable to nonshared environmental influences. They did not find room for shared environmental influences. Finkel and her colleagues, however, used a separation–reunion procedure originally designed for assessing temperament, and this adapted attachment measure was only moderately associated with the Strange Situation Procedure.

In a relatively large-scale twin study on attachment in preschool children, O'Connor and Croft (2001) observed 110 MZ and DZ twin pairs in the strange situation procedure and used the preschool coding manual developed by Cassidy and Marvin in cooperation with the MacArthur Working Group on Attachment (1992). As in the earlier sibling study (Van IJzendoorn et al., 2000), they found substantial similarity of attachment security between the twin siblings, with a higher degree of concordance in MZ than DZ twins. They argued that their findings were consistent with a modest role for genetic influence (14%) and with substantial influences of shared (32%) and nonshared (53%) environment (O'Connor & Croft, 2001). They did not find a mediating role for temperamental differences (parent report and observer report) in explaining similarities or dissimilarities in attachment between the siblings. Although this investigation presented the first behavior genetic modeling of attachment data, the role of genetic influences may have been underestimated. The procedure to observe and classify attachment security in preschoolers still is less well validated than the classic Ainsworth Strange Situation Procedure for infants (Solomon & George, 1999). The error component in the preschool system may therefore be larger than for the infant system, which may have inflated estimates of the nonshared environment at the cost of the genetic or shared environment component.

The current study focused separately on disorganized attachment defined as the (sometimes momentary) breakdown of the organized strategy to deal with stress (Main & Solomon, 1990) and on the organized attachment patterns (secure, avoidant, and resistant) as presented in Ainsworth et al. (1978). Traditional family research presupposes that parental sensitivity as part of the (non)shared environment is an important determinant of attachment security or nonsecurity (DeWolff & Van IJzendoorn, 1997). Thus, the influence of a genetic component on the organized attachment strategies was expected to be small. With respect to the disorganized attachment group, the empirical evidence does not unequivocally suggest a major role for the shared environment. Some observational studies without a behavioral genetic design confirmed the role of (abusive, frightening, and frightened) parenting in the emergence of disorganization (Lyons-Ruth & Jacobvitz, 1999; Van IJzendoorn, Schuengel, & Bakermans-Kranenburg, 1999). In contrast, Spangler, Fremmer-Bombik, and Grossmann (1996) found that attachment disorganization was best predicted by newborn behavioral organization in terms of orienting ability and regulation of state instead of parenting. Furthermore, a small molecular-genetic investigation found some evidence for the role of the dopamine D4 receptor (DRD4) gene polymorphism (Lakatos et al., 2000; Lakatos et al., 2002). Therefore, diverging genetic mechanisms may determine the development of disorganized and organized attachment patterns, and separate hypotheses and subsequent analyses are warranted.

In sum, the following hypotheses were tested. First, although the available evidence seems to be inconclusive, we expected a role for a genetic component in disorganized attachments as suggested by Spangler et al.'s (1996) longitudinal study and by Lakatos et al.'s (2000) pioneering molecular-

genetic study. Second, we expected that individual differences in organized patterns of attachment behavior would show a substantial influence of the shared environment. Our main hypothesis concerned attachment security versus nonsecurity, which constitutes the basic split in attachment classifications (Ainsworth et al., 1978). Our third hypothesis concerned the heritability of temperamental reactivity. Temperamental reactivity was expected to be highly genetically influenced, whether temperament is observed by independent observers or reported by the parents as in the current study (Bouchard, & Loehlin, 2001; Emde et al., 1992; Goldsmith, Lemery, Buss, & Campos, 1999). We also tested whether temperamental similarities were responsible for concordance in attachment classifications (Fearon, 1999; Van IJzendoorn, 1995b).

Method

Participants

Participants came from two twin studies, conducted in Leiden, Netherlands and London. The two studies used similar designs and measures.

The Leiden twin study. The sample consisted of 76 twin pairs, with 27 MZ and 49 DZ same-sex pairs. The families were recruited through the Netherlands Twin Register (Boomsma, Orlebeke, & van Baal, 1992), which contains 40% to 50% of all multiple births after 1986. DZ pairs are somewhat overrepresented among same-sex twins of this age because of the dizygosity of multiple births that are the result of fertility treatment. Eighteen families in our sample reported fertility treatment. Most families were middle class. On a scale for educational level, ranging from 1 to 7, the mean level was 4.5 ($SD = 1.7$). The mean age of the mothers was 32 years ($SD = 3.6$). The children were observed in Ainsworth's strange situation procedure when they were between 12 and 14 months of age (after correction for prematurity: $M = 52.6$ weeks and $SD = 4.8$). The two children of the same twin pair were seen separately, with an intervening period of 1 week.

The London twin study. The sample consisted of 62 same-sex twin pairs, with 30 MZ and 32 DZ twin pairs, living in and around London. The families were recruited through the Multiple Births Foundation of Queen Charlotte's and Chelsea Hospital in London. Most of the families were middle class and well educated. The mean age of the mothers was 35 years ($SD = 5.4$). The twins were between 12 and 13 months when observed in Ainsworth's strange situation procedure (after correction for prematurity: $M = 54.2$ weeks and $SD = 3.1$). The two children of the same twin pair were observed on the same day. The London sample also included different-gender twins: There were 19 DZ twins of different gender (one boy, one girl). Twin studies usually use same-sex DZ twin pairs because they are a better comparison group for MZ twin pairs, who of course are always of the same gender (Plomin et al., 2001). Although different-gender pairs may be an interesting contrast compared with same-gender pairs (see Van IJzendoorn et al., 2000), they were excluded here from most analyses because the small different-gender subset would preclude statistical tests of gender influences (see also Deater-Deckard & O'Connor, 2000). To test the robustness of our findings, the critical test of the genetic model for the disorganized versus organized, and the secure versus nonsecure split was also performed for the set including the different-gender pairs.

Design and Procedure

All infants were observed in Ainsworth's Strange Situation Procedure for assessment of mother–child attachment (Ainsworth et al., 1978). In both studies the mothers were asked to assess the temperament of their children by completing a questionnaire for each child separately. The mothers of the Leiden twins received the Infant Behavior Questionnaire (IBQ; Rothbart, 1981) at home 2 months before they came to the laboratory. The mothers of the London twins were asked to complete the Infant Characteristics Questionnaire (Bates, Freeland, & Lounsbury, 1979) at home 2 months before the Strange Situation assessment.

Measures

Strange Situation Procedure. The well-known and standard Strange Situation Procedure was used to assess infant–mother attachment security in both samples. The procedure consists of three stressful components: the infant enters with the mother an unknown laboratory playroom; a stranger comes in and tries to play with the infant; the mother leaves the room twice for a brief period. In particular, infants' behavior at reunion with the mother is essential for coding the quality of the attachment relationship. Upon reunion, secure infants (B category) seek proximity but after being cuddled or otherwise reassured, explore the environment again. Non-secure-avoidant infants (A category) avoid the mother and seem to remain focused on the environment, whereas non-secure-resistant infants (C cate-

gory) display attachment behavior and seek proximity, but at the same time resist contact with the mother (Ainsworth et al., 1978). Some secure or nonsecure attachment relationships appear to be characterized by the (sometimes momentary) absence or breakdown of an otherwise organized strategy, hence defined as disorganized attachment (D category; Main & Solomon, 1990). Indices of disorganized attachment behavior expressed in the strange situation procedure are: sequential or simultaneous display of contradictory behaviors, such as distress and avoidance; undirected or misdirected movements and expressions; stereotypes and anomalous movements or postures; freezing or stilling behaviors; expressions of fear or apprehension regarding the parent; and clear indexes of confusion and disorganization in the presence of the parent (Main & Solomon, 1990). In all studies, strange situations were coded by experienced coders who reached satisfactory intercoder reliability on both three-way classifications (kappas $>.73$) and four-way classifications (kappas $>.70$).

Temperamental reactivity. In the Leiden twin sample, the Infant Behavior Questionnaire (Rothbart, 1981) was used. The IBQ is an instrument designed to assess temperament by asking caregivers about particular behaviors of infants. Caregivers are asked to respond to most items on the basis of the behavior of the infant during the previous week (and for some items the previous 2 weeks). The IBQ consists of six subscales: Activity Level, Smiling and Laughter, Fear, Distress to Limitations, Soothability, and Vocal Activity. A seventh scale, Overall Reactivity, was computed by subtracting the standardized scores on Smile and Laughter and Activity from the standardized score on Distress to Limitations (see Rothbart, 1986). For the Smile and Laughter scale, Cronbach's alphas for the first and second twins were .77 and .78, respectively. For the Activity scale, Cronbach's alphas for the first and second twins were .82 and .84, respectively. For the Distress to Limitations scale, Cronbach's alphas for the first and second twins were .73 and .75, respectively.

In the London sample, the Infant Characteristics Questionnaire (Bates et al., 1979) was used. This questionnaire consisted of 24 items and was designed to assess perceived infant temperament. Four subscales can be distinguished: Fussy/Difficult, Unadaptable, Dull, and Unpredictable. The Fussy/Difficult scale was selected to be combined with the IBQ Overall Reactivity scale because in previous work (Goldsmith, Rieser-Danner, & Briggs, 1991) this scale correlated strongly with the Distress to Limitations scale, which is part of the Overall Reactivity scale as assessed by the IBQ. Cronbach's alphas for the Fussy/Difficult scale for the first and second twins were .85 and .82, respectively. The variables were standardized within studies before being combined into one variable.

Zygosity determination. In the Leiden sample, zygosity was determined with the Zygosity Questionnaire for Young Twins (Goldsmith, 1991). This questionnaire was completed three times by the mother: at 10 months of age, at 12 months of age, and at 3 years of age. Questions concern similarities of physical features of the twins and experiences of mistaking one twin for another. To validate our decision about the twins' zygosity, Rietveld et al.'s (2000) discriminant equation was used. Although this equation was developed for 6-year-old children, it seemed reasonable to use it for validation of our decision in 3-year-olds. According to this equation, all but one pair were correctly diagnosed. This pair was rediagnosed as DZ.

For a substantial number of the London twins information about placentation was available; this way, 47% of these twins were identified as MZ. For the other twins, zygosity was determined using a genetic test (Freeman et al., 1997). Parents were given a test kit and instructions when they were at the laboratory for the Strange Situation Procedure. They were asked to take the DNA samples of their twins (a sample of cheek cells) at home and to send them to Freeman's laboratory for zygosity determination.

Statistical Analyses

After presenting basic descriptive data on the distribution of attachment classifications in our twin studies as compared with normative distributions, the simple percentages of concordance of MZ and DZ twin pairs for disorganized and secure attachment classifications are first provided. These percentages were obtained by dividing the number of concordant pairs (e.g., both infants secure or both infants nonsecure) by the total number of twin pairs; the resulting percentages can be compared with the percentages of concordance as reported in other twin studies. Second, the pairwise and the probandwise concordance rates (which are commonly preferred in genetic epidemiology) within MZ and DZ twin pairs are presented. For the pairwise concordance, the number of concordant pairs was divided by the number of pairs in which at least one of the twins showed the classification. The probandwise concordance was computed by dividing the number of infants with a specific attachment classification in

concordant twin pairs (with both twins sharing that classification) by the total number of infants with that attachment classification. For genetic modeling these concordances were not used but instead the contingency tables with the raw frequencies of classifications for MZ twins and DZ twins were inserted (see the following). The genetic analyses were performed with the program Mx (Neale, Boker, Xie, & Maes, 1999). Although the number of twin pairs in the current study was restricted, the sample size was comparable to previous twin samples with time-consuming observational methods of data collection (e.g., Leve et al., 1998; O'Connor & Croft, 2001).

To avoid the presentation of overlapping data sets and to conduct independent analyses, we differentiated two levels of data analysis. The first level concerned disorganized attachment because it is considered to be orthogonal to the organized secure and nonsecure attachment strategies (Main & Solomon, 1990; Van IJzendoorn et al., 1999). On the second level only twin pairs were included that were both classified as attached in an organized way. Thus, the second and most important level in the current investigation concerned the split of the organized attachments into secure and nonsecure classifications. Disorganization of one or both twins was an exclusion criterion. Inclusion of forced secondary classifications given to infants who received a primary classification as disorganized would lead to overlapping analyses and would weaken the homogeneity and clarity of the organized categories. This stepwise procedure avoided capitalizing on the concordances of the largest subset of secure attachments in estimating the heritability of the attachment classification. The number of nonsecure (avoidant or resistant attachment) twin pairs was too small for genetic modeling to be warranted.

Results

Distributions and Concordances of Attachment: Descriptive Outcomes

Table 1 presents the distributions of the four attachment patterns: avoidant (A), secure (B), resistant (C), and disorganized (D). The distribution of the current samples was significantly different from the global distribution (derived from a meta-analysis of various samples around the world by Van IJzendoorn et al., 1999) in a multinomial test, $\chi^2(df = 3) = 26.68$, $p < .01$. The secure children were underrepresented ($z = -2.61$, $p < .01$) and the nonsecure-resistant children were overrepresented ($z = 4.25$, $p < .01$). The percentages of non-secure-avoidant and disorganized children were comparable to the percentages in the global distribution ($z = .25$ and $z = 1.34$, respectively).

Table 2 presents the cross-tabulation of attachment classifications within pairs and across samples. For MZ twins, the percentages of concordance were 72% for disorganized versus organized (D-nonD) attachment and 56% for secure versus nonsecure (B-nonB) attachment; for DZ twins, the concordances were 73% for D-nonD attachment and 60% for B-nonB attachment. Twenty MZ infants were classified as disorganized. Four of them were part of (2) MZ twin pairs, and in 16 MZ twin pairs one of the twins was disorganized. Thus, the pairwise concordance was 11% (2 of 18). For the probandwise concordance, the number of index cases (in our case, the number of disorganized infants) in concordant twin pairs was divided by the total number of index cases; therefore, the probandwise concordance for MZ twins was 20% (4 of 20). The pairwise concordance of disorganized attachment for DZ twins was 15% (4 of 26), and the probandwise concordance was 27% (8 of 30). For secure attachment, the concordance rates for MZ twins were 42%

Table 1
Child–Mother Attachment Classification Distributions per Study and per Zygosity for All Children

Zygosity	Study	Avoidant *n* (%)	Secure *n* (%)	Resistant *n* (%)	Disorganized *n* (%)	Total *n*
Identical						
	Leiden	5 (9)	32 (59)	4 (7)	13 (24)	54
	London	13 (22)	29 (48)	11 (18)	7 (12)	60
	Total	18 (16)	61 (54)	15 (13)	20 (18)	114
Fraternal						
	Leiden	21 (21)	47 (48)	8 (8)	22 (22)	98
	London	4 (6)	29 (45)	23 (36)	8 (13)	64
	Total	25 (15)	76 (47)	31 (19)	30 (19)	162
Total		43 (16)	137 (50)	46 (17)	50 (18)	276
Global distribution		15%	62%	9%	15%	

Table 2
Cross-Tabulation of Attachments of First and Second Children per Zygosity

Zygosity	Attachment of the first child	Attachment of the second child				
		Avoidant	Secure	Resistant	Disorganized	Total
MZ	Avoidant	3	5	0	0	8
	Secure	3	18	3	6	30
	Resistant	1	4	2	2	9
	Disorganized	3	4	1	2	10
	Total	10	31	6	10	57
DZ	Avoidant	7	4	1	2	14
	Secure	1	22	5	5	33
	Resistant	1	5	9	1	16
	Disorganized	2	12	0	4	18
	Total	11	43	15	12	81

Note. MZ = monozygotic; DZ = dizygotic.

(pairwise) and 59% (probandwise), and for DZ twins the concordance rates were 41% (pairwise) and 58% (probandwise). For avoidant attachment, the concordance rates for MZ twins were 20% (pairwise) and 33% (probandwise), and for DZ twins the concordance rates were 39% (pairwise) and 56% (probandwise). Finally, for resistant attachment, the concordance rates for MZ twins were 15% (pairwise) and 27% (probandwise), and for DZ twins the concordance rates were 41% (pairwise) and 58% (probandwise). These percentages stressed the importance of the environment, not only for disorganized and secure attachment but also for the avoidant and the resistant attachment classifications.

Modeling Genetic, Shared, and Nonshared Environmental Components in Attachment

In behavioral genetic analyses, the similarity of pairs of twins is decomposed into similarity due to additive genetic factors (A) and similarity due to shared environmental experiences (C), and dissimilarity is accounted for by unique or nonshared environmental influences and measurement error (E). The genetic analyses were performed with the program Mx (Neale et al., 1999), which provides estimates of the parameters in the ACE model (A, genetic factors; C, shared environment; E, nonshared environment and measurement error) and an overall chi-square goodness-of-fit index. A small chi-square corresponds to good fit, and a large chi-square corresponds to bad fit (and lower values for p). The significance of the estimated parameters was tested using a nested model design in which the model was reestimated with the estimated parameter fixed to zero. The change in chi-square between the fit of the complete ACE model and the more parsimonious model (AE when C is fixed to zero, CE when A is fixed to zero) indicates the significance of the estimated parameter. A nonsignificant difference in the chi-square values between two nested models implies that the additional specification (one of the parameters fixed to zero) does not significantly reduce the fit and that the new, more restricted model is accepted, because more parsimonious, simpler models are more replicable. Moreover, Akaike's Information Criterion (AIC) is provided as a goodness-of-fit index. AIC is functionally related to chi-square and degrees of freedom. Good fit with only a few free parameters to estimate yields a small chi-square with relatively large degree of freedom, leading to a large, negative AIC. AIC takes parsimony into account and thus favors simpler models. The models were fit to contingency table data with frequencies of classifications for MZ twins and DZ twins.

Tables 3 and 4 present the results of behavior-genetic modeling of disorganized and secure attachment. The first analyses pertained to the concordances of organized versus disorganized attachments. The model with all three factors included (ACE; genetic, shared environmental, and unique environmental factors) fitted the data adequately ($\chi^2 = 1.83$, $p = .61$, AIC = −4.170), but the more parsimonious model with only unique environment and measurement error (E) should be preferred ($\chi^2 = 2.50$, $p = .78$, AIC = −7.497) because the difference in chi-square was not significant and the E model is simpler than the ACE model. Only unique environment and measurement error (E)

Table 3
ACE Models of Attachment (Organized vs. Disorganized)

	A	C	E	χ^2	*df*	*p*	AIC
ACE	.00[a]	.14	.86	1.83	3	.61	−4.170
AE	.16	–	.84	2.08	4	.72	−5.923
CE	–	.14	.86	1.83	4	.77	−6.170
E	–	–	1.0	2.50	5	.78	−7.497

Note. *n* (monozygotic) = 57 pairs; *n* (dizygotic) = 81 pairs. ACE = A—genetic factors, C—shared environment, and E—nonshared environment and measurement error; AIC = Akaike's Information Criterion. [a]rounded to two decimals. E is the preferred model.

Table 4
ACE Models of Attachment (Secure vs. Nonsecure)

	A	C	E	χ^2	*df*	*p*	AIC
ACE	.00[a]	.52	.48	5.15	3	.16	F − 0.849
AE	.53	–	.47	9.35	4	.05	1.349
CE	–	.52	.48	5.15	4	.27	−2.849
E	–	–	1.0	16.30	5	.01	6.302

Note. *n* (monozygotic) = 39 pairs; *n* (dizygotic) = 55 pairs. ACE = A—genetic factors, C—shared environment, and E—nonshared environment and measurement error; AIC = Akaike's Information Criterion. [a]rounded to two decimals. CE is the preferred model.

explained the variance in disorganization (95% confidence interval = .44 ∼ 1.00). Neither the CE model nor the AE model appeared to fit the data significantly better than the model with only unique environment and measurement error (see Table 3). A comparable result was found when the opposite gender pairs were included (E model: $\chi^2 = 1.44$, $p = .92$, AIC = −8.557). It was tested whether the model for boys was equal to that for girls, or whether different models fitted the data for girls and boys more adequately. The ACE model without equality constraints ($\chi^2 = 5.98$, $df = 7$, $p = .54$, AIC = −8.024), that is, the model allowing for different models for boys versus girls, did not provide a significantly better fit to the data than the model with equality constraints ($\chi^2 = 6.60$, $df = 10$, $p = .76$, AIC = −13.394), and this was also true of the E model. The model assuming equal models for boys and girls was thus accepted as the more restricted, simpler model. In the same vein, it was tested whether the same model was applicable to twins from the Leiden sample and twins from the London sample. Again, both the ACE and the E model pointed to the adequacy of the models with equality constraints, showing that the same model was applicable to twins from both labs. It should be noted, however, that the restricted sizes of the subsets may have limited the chances of finding diverging models.

The second series of analyses pertained to the concordances of secure versus nonsecure attachments. Pairs with one or two disorganized children were excluded to conduct independent analyses. The model with all three factors included (ACE; genetic, shared environmental, and unique environmental factors) fitted the data adequately ($\chi^2 = 5.15$, $p = .16$, AIC = −0.849), but the more parsimonious CE model should be preferred ($\chi^2 = 5.15$, $p = .27$, AIC = −2.849), as the difference in chi-square is not significant and the CE model is simpler than the ACE model (note that the larger negative AIC also favored the CE model). Fifty-two percent of the variance in attachment security was explained by shared environmental influences (C, 95% confidence interval = .23 ∼ .74), and 48% of the variance was explained by unique environment and measurement error (E, confidence interval = .26 ∼ .77). Further restriction of the model with both A and C fixed to zero (the E model) reduced the fit significantly ($\chi^2 = 16.30$, $p < .01$, AIC = 6.302), indicating the CE model as the plausible model (see Table 4). Genetic modeling including the opposite gender pairs yielded comparable results, although the effect of the common environment was lower (CE model: $\chi^2 = 2.63$, $p = .62$, AIC = −5.370, 43% C, 57% E). Parallel to the analyses of disorganized attachment, it was tested whether the model for boys was equal to that for girls, or whether different models fitted the data for security of girls and boys more adequately. The ACE model without equality constraints ($\chi^2 = 12.69$, $df = 7$, $p = .08$, AIC = −1.315), that is, the model allowing for different models for boys versus girls, did not provide a better fit to the data than the model with equality constraints ($\chi^2 = 13.02$, $df = 10$, $p = .22$, AIC = −6.984), and this was also true of the CE model. The model assuming equal models for boys and girls was thus accepted as the more restricted, simpler model. In the same vein, it was tested whether the same model was applicable to twins from the Leiden sample and twins from the London sample. Again, both the ACE and the CE model pointed to the adequacy of the models with equality constraints, showing that the same model was applicable to twins from both labs.

Role of Temperament

Means and standard deviations on temperamental reactivity (standardized scores) for the four attachment categories are presented in Table 5. The

Table 5
Means and Standard Deviations of Temperamental Reactivity (Z Scores) for the Four Attachment Classifications

	Temperamental reactivity					
	First child			Second child		
Attachment classification	*n*	*M*	*SD*	*n*	*M*	*SD*
Avoidant	22	−0.08	0.9	21	−0.12	0.8
Secure	63	−0.16	1.0	74	−0.06	F1.0
Resistant	25	0.30	1.1	21	0.40	0.8
Disorganized	28	0.32	1.0	22	0.17	F1.3
Total	138	0.04	1.0	138	0.04	F1.0

Table 6
ACE Models of Temperamental Reactivity

	A	C	E	χ^2	*df*	*p*	AIC
Reactivity							
ACE	.66	.11	.23	2.62	3	.45	−3.379
AE	.77	–	.23	2.99	4	.56	−5.008
CE	–	.57	.43	15.14	4	.00	7.135
E	–	–	1.0	69.58	5	.00	59.580

Note. *n* (monozygotic) = 57 pairs; *n* (dizygotic) = 81 pairs. ACE = A—genetic factors, C—shared environment, and E—nonshared environment and measurement error; AIC = Akaike's Information Criterion. AE is the preferred model.

correlation between temperamental reactivity in MZ twin pairs was $r = .77$ ($n = 57$, $p < .001$). For DZ twins the correlation was $r = .44$ ($n = 81$, $p < .001$). The difference in correlations between MZ and DZ twins pointed to a genetic component. The important role of genetics in temperamental reactivity was supported by the results of modeling the genetic, shared, and nonshared components with Mx. Table 6 presents the outcomes of these analyses. The AE model was the preferred model ($\chi^2 = 2.99$, $p = .56$, AIC = −5.008), and the model indicated that 77% of the variance in temperamental reactivity was explained by genetic factors (A, 95% confidence interval = .58 ~ .98), with 23% attributed to unique environmental factors and measurement error (E, 95% confidence interval = .16 ~ .32). The ACE model ($\chi^2 = 2.62$, $p = .45$, AIC = −3.379) showed hardly any influence of shared environment on temperamental reactivity (11%).

The association among temperamental reactivity and the four-way attachment classifications was not significant, $F(3, 134) = 2.23$, $p = .09$, and $F(3, 134) = 1.53$, $p = .21$, for the first and second child, respectively. Searching for factors explaining concordance and nonconcordance in infant pairs growing up with the same parent or caregiver, absolute difference scores for temperamental reactivity of the first and the second infant within each pair in the set of twins were computed. The first analysis pertained to attachment disorganization. Mean difference scores for concordant (disorganized vs. organized) pairs ($M = .68$, $SD = .62$, $n = 100$) and nonconcordant pairs ($M = .60$, $SD = .68$, $n = 38$) were not significantly different. The same was true of concordance in attachment security. Mean difference score for concordant (secure vs. nonsecure) pairs ($M = .73$, $SD = .64$, $n = 64$) and nonconcordant pairs ($M = .61$, $SD = .60$, $n = 30$) were not significantly different. A logistic regression analysis was conducted to test whether temperament could predict concordance in attachment classification. The temperament scores of both children were entered first, followed by their interaction. Temperament did not predict the concordance variables.

Discussion

Attachment theory emphasizes the environmental causation of individual differences in attachment security and stresses the important role of parental sensitivity. Indeed, contemporary work on attachment makes the even more specific claim that the primary causes of individual differences in attachment security are of the shared environmental kind (O'Connor et al., 2000). In particular, the model of intergenerational transmission of parental attachment representations to infant patterns of attachment behavior implies a strong environmental effect (Hesse, 1999; Main et al., 1985; Van IJzendoorn, 1995b), although this model does not preclude a genetic mechanism of transmission (Main et al., 1985). Genetic factors may come into play when attachment relationships become disorganized. For disorganized attachment, theory and nongenetic research stresses the role of (frightened or frightening) parenting, and disorganization is thought to be caused by (shared or unique) environmental factors such as loss or trauma in the parents around the birth of their child (Main & Hesse, 1990; Schuengel, Bakermans-Kranenburg, & Van IJzendoorn, 1999). Nevertheless, in their molecular-genetic study, Lakatos and colleagues (Lakatos et al., 2000; Lakatos et al., 2002) found DRD4 gene polymorphism to be associated with disorganization, and that of course stresses its possible genetic basis.

The current behavioral genetic study found considerable evidence to support the decisive role of environmental factors in the development of (non)secure attachment, with concordances for MZ and DZ twins that leave some room for shared and

unique environmental influences. Behavior genetic modeling indicates that the heritability of disorganized and secure attachment behavior is negligible. The unique environment seems responsible for disorganization of attachment, and the shared environment counts for more than half of the variance in secure attachment. This not only represents confirmation of one of the basic assumptions of attachment theory but also seems to fit well with research that has documented a robust association between maternal representations of attachment and infant attachment security (around $r^2 = .25$; see Van IJzendoorn, 1995b).

In an age when shared environmental theories of development have been rejected by some behavior-geneticists (e.g., Rowe, 1994; Scarr, 1992), the finding of a substantial shared environment influence is noteworthy. For example, in their authoritative textbook on behavioral genetics, Plomin et al. (2001) stated that for most domains of psychology environment is important and explains about half of the variance in traits, attitudes, and behavior patterns, but it ''is generally not shared family environment that causes family members to resemble each other'' (p. 298). The unique or nonshared component is supplemented with genetic influences, leaving little or no room for the shared environment. Bouchard and Loehlin (2001) described moderate shared environment effects in altruism, sociability, and autonomy in adolescence, and in attitudes toward love or love styles in adulthood. The authors commented on this latter outcome (see Waller & Shaver, 1994) that the combination of small heritability and modest shared environment of love styles belongs to ''a very rare class of phenotype, one with little or no genetic variance'' (p. 263).

An alternative interpretation of our results may stress the dyadic nature of the attachment construct. Infant attachment may be considered a characteristic of the relationship with the parent or caregiver, whereas later in childhood the internalization of attachment experiences may lead to a more stable working model of attachment residing within the child regardless of his or her relationships. It may even be argued that attachment security as assessed in the Strange Situation Procedure necessarily involves the parent as an interactor, which may elevate the contribution of shared environment to the measured characteristic. However, Deater-Deckard and O'Connor (2000) showed that there is no necessary link between the dyadic nature of a construct and its measurement and the role of shared environment. In their twin study on mutuality, they found that heritability and nonshared environment each accounted for about half of the variance in observed mother–child dyadic mutuality, whereas shared environment was negligible.

Several behavior geneticists have suggested that shared environmental factors are likely to be more significant in infancy and early childhood than later in life, and genetic studies of individual differences in mental development and temperament confirm this view (e.g., Plomin, 1994; Plomin & Daniels, 1987). The only study addressing the issue of heritability of attachment beyond infancy is O'Connor and Croft's (2001) twin study on preschoolers. Even in preschool, these authors found evidence for a small role of genetics and a substantial, albeit smaller, shared environmental influence. Whether shared environmental influences are evident in measures of attachment in later childhood and adulthood remains an important question to be addressed by future research. Longitudinal genetic research would allow for the estimation of genetic and environmental influences at different developmental stages and of their influence on age-to-age changes in attachment security. The internal working models view of attachment would predict that continuity over time in patterns of attachment would be driven by shared environmental factors (Fraley, 2002), a prediction that could be elegantly tested by longitudinal genetic studies of attachment (Fearon, 1999).

The only study that failed to replicate the finding of the impact of shared environment on attachment security was conducted by Finkel and her colleagues (Finkel et al., 1998; Finkel & Matheny, 2000). Indeed, although the study of Finkel and Matheny (2000) suggested the possibility of genetic influences on attachment security, their genetic estimate appears to derive from a low concordance for DZ twins (44%) rather than from an exceptionally high concordance for MZ twins (63%). Given the robust finding of 62% concordance for nontwin siblings from which the Finkel et al. (1998) percentage significantly deviates, multinomial $\chi^2(df = 1) = 8.80$, $p < .01$ (see Van IJzendoorn et al., 2000), the findings of Finkel and her colleagues seem to suggest a problem with the representativeness of their DZ group. Another problem might be the validity of their nonstandard attachment assessment procedure, which was originally designed to measure temperamental differences. Although Finkel and her colleagues validated their procedure against the standard strange situation procedure, the association was not perfect (78% agreement), and the use of the standard procedure might have led to different concordance rates. It is clear from our study as well as numerous other

investigations (Bouchard & Loehlin, 2001; Emde et al., 1992; Goldsmith et al., 1999) that temperamental differences are largely genetic.

A noteworthy finding from this investigation of attachment in families with twins is the substantial influence of nonshared environmental factors, in particular, in the development of disorganized attachment. Much of the variance in individual differences in attachment appears to be attributable to differences within families, not between them, as traditional approaches to attachment might suggest. Indeed, the nonshared environment is evident in all (organized and disorganized) patterns of attachment behavior observed in Ainsworth's Strange Situation Procedure. If nonshared influences on attachment can be shown to represent meaningful and reliable differences in family relationships, researchers interested in the causes and developmental consequences of attachment need to develop new ways of conceptualizing and investigating this important domain of socioemotional development. Of course, some nonshared influences on different infants within the same family may be triggered by differences in temperament between the siblings. However, in our twin study it was not possible to trace any effect of temperamental (dis)similarity on the concordance of attachment. It should be noted, however, that in the current study temperament assessment was based on parental reports, whereas attachment was measured in an observational procedure. Some authors have argued that temperament should be assessed by independent observers in an experimental setting to reach a sufficiently valid index of this complex construct.

Part of the unique or nonshared component in attachment may have arisen from measurement error, in particular, in the newly developed coding system for disorganization (Main & Solomon, 1990). Given the satisfactory psychometric properties of the strange situation procedure—even concerning disorganized attachment (Van IJzendoorn et al., 1999)—it seems unlikely that measurement error can account for a large proportion of the discordant cases found in this study. As an illustration, consider that if nonshared influences were absent, assessments of twins' attachment security could be thought of as repeated assessments of the same child (assuming that genetic influences are zero). The correlation between twins would thus represent a direct estimate of the reliability (test–retest or otherwise) of the Strange Situation Procedure. Certainly, estimates of the interrater reliability of the procedure would lead one to expect a correlation between twins of the order of .70 to .80 if this were the case (Fearon, 1999). The long-term predictive validity of the Strange Situation Procedure would also suggest higher levels of reliability (Main & Cassidy, 1988; Waters, Hamilton, & Weinfield, 2000; Waters, Merrick, Treboux, Crowell, & Albersheim, 2000; Waters, Weinfield, & Hamilton, 2000). Infant disorganization, for example, has been shown to predict dissociative tendencies in adolescence (Carlson, 1998). Of course, it should be noted that concerns about the test–retest reliability of the Strange Situation Procedure have been raised in recent times (Belsky, Campbell, Cohn, & Moore, 1996, including infant–father strange situations; Thompson, 1997; but see Fraley, 2002), underlining the importance of further research in this area. Nevertheless, the weight of evidence seems to favor the view that the Strange Situation Procedure is a reliable instrument, at least in infants between 12 and 16 months of age with their mothers (Solomon & George, 1999), and hence that differences between twins are likely to represent more than mere measurement error.

The current findings fail to support the hypothesis that the so-called transmission gap might be closed by genetic factors. Several studies provided support for the basic model (Main et al., 1985) of causal relations among parental attachment representations, parental sensitivity, and infant–parent attachment, but a large and quantifiable transmission gap (Van IJzendoorn, 1995b) between parent and infant attachment still remains to be closed (Meins, 1999; Pederson et al., 1998; Raval et al., 2001; Rosenblum, McDonough, Muzik, Miller, & Sameroff, 2002). The current investigation showed that genetic transmission may only be of minor import to the transmission of the organized attachment strategies from parents to their infants, although one should be cautious in drawing conclusions from behavior genetic studies for the outcome of traditional parent–offspring investigations. The role of genetics in the transmission of attachment across generations may only be uncovered in twin and adoption or foster studies that not only include assessments of infant attachment and parental sensitivity but also adult attachment representations in the parent of the twins or in adoptive or foster parents (e.g., the Dozier, Stovall, Albus, & Bates, 2001, study on foster parents). The search for mechanisms that help close the transmission gap may now concentrate on parenting behaviors different from the classic sensitivity concept (Van IJzendoorn, 1995a, 1995b), but, maybe more important, also on unique environmental factors shaping the infant's patterns of attachment behavior. In particular, disorganization

of attachment seems liable to unique environmental influences. On the other hand, a molecular-genetic study found some associations with a DRD4 polymorphism (Lakatos et al., 2000; Lakatos et al., 2002). Our findings point to the necessity of replicating the Lakatos et al. studies and we are currently collecting DNA samples from the twins involved in our investigation to test whether behavioral-genetic and molecular-genetic approaches in the same participants show converging evidence.

In future studies, it is also important to include parenting in the modeling of genetic and environmental components of attachment. The development of attachment provides a unique forum for exploring (shared and nonshared) environmental processes because clear theoretical predictions can be made about expected mechanisms and because high-quality observational instruments have been well established. In search for the meaning of the (non)shared environment in the emergence of attachment security, parental sensitivity as assessed in interactions with both children of a twin pair may be crucial. This approach might show that the unique environment (partly) consists of parental behavior that intentionally or accidentally differentiates the developmental pathways of both children within a twin pair. Genetic and (non)shared environmental (children's) influences on parental sensitivity should be determined, and the link between shared environmental influences on attachment security and shared environmental components of parental sensitivity should be examined, thus testing a key prediction of attachment theory. The inclusion of sufficiently large numbers of non-secure-avoidant and non-secure-resistant infants would be important to verify our preliminary finding of a large shared environmental factor for avoidant and resistant attachment (Bakermans-Kranenburg et al., 2003) and to clarify the interplay between insensitivity and temperament in creating diverging nonsecure pathways for children within the same family.

The concept of sensitivity may explain why children with varying ways of processing information might experience sensitive parents in the same way. Sensitive parents know how to adapt to the diverging perceptions and needs of their offspring and are inclined to behave differently to be equally sensitive to the different children in their family (O'Connor & Croft, 2001). Thus, various parenting behaviors may constitute sensitive parenting uniquely fitted to the needs of a specific child. It could be exactly because of this agility of parental sensitivity that it may be hard to measure in empirical research using standard settings and coding systems. Furthermore, the role of differential parental (in)sensitivity to each of the twins should be studied as a possible explanation of the considerable nonshared variance in attachment. In fact, it should not be considered self-evident that parental sensitivity is representing shared environment more than unique influences. Longitudinal studies on parental sensitivity and attachment in twins, siblings, and unrelated children may open exciting avenues for uncovering the interplay among genes, shared environment, and nonshared environment in children's socioemotional development.

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